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ORIGINAL RESEARCH PAPER

Enhancing Learning of Motion Concepts through Conceptual Frameworks

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ABSTRACT

Drawing on recent advances in physics education research as well as practical insights from classroom experiences, the article proposes a set of strategies for effective implementation. These include contextualizing learning within real-world phenomena, integrating interactive technologies into instruction, and designing inquiry-based learning activities that promote active engagement. A central contribution of this work lies in its dual theoretical and practical orientation. The article not only identifies the pedagogical significance of conceptual tools but also demonstrates how their structured integration can be systematically applied to the teaching of motion. This structured approach represents the main novelty of the study, as it provides teachers with a clear framework for bridging theory and classroom practice. The discussion further addresses common challenges faced in physics instruction, such as persistent misconceptions and limited student engagement. In response, it offers strategies grounded in both educational theory and empirical practice, ensuring that the suggested frameworks are both conceptually sound and practically applicable. In conclusion, the article emphasizes that prioritizing conceptual understanding over purely procedural knowledge can significantly improve student motivation, retention of core ideas, and scientific reasoning skills. Such a shift underscores the transformative potential of conceptual frameworks in advancing the teaching and learning of motion.

Keywords:
Motion in physics, conceptual frameworks, physics education, motion concepts, interactive learning, improving physics education.

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1. INTRODUCTION

A deep understanding of motion concepts (position, displacement, velocity, acceleration, and Newton's laws) is essential for developing students' reasoning and problem-solving skills. However, research shows that learning these concepts is hindered by their abstract nature, overreliance on traditional teaching methods, and lack of connection to real-life contexts. To address these challenges, recent studies emphasize the role of conceptual tools (concept maps, mental models, simulations, and visual representations) in promoting deeper comprehension and correcting misconceptions.

Despite its foundational importance, students ranging from secondary school learners to university undergraduates frequently struggle with motion-related concepts. Research has consistently shown that these difficulties often arise from the abstract nature of motion, inadequate integration of real-life contexts, and a reliance on traditional teaching methods that emphasize rote memorization over conceptual understanding. Misconceptions such as believing that a continuous force is required to sustain motion or that heavier objects fall faster persist even after formal instruction and can significantly hinder students' ability to engage with more complex physical systems.

To address these challenges, recent studies in physics education have emphasized the role of conceptual frameworks—such as simulations, mental models, and visual representations—as tools for promoting deeper understanding, addressing misconceptions, and supporting cognitive engagement.

These frameworks include concept maps, mental models, dynamic simulations, and other representational tools that help students visualize, organize, and relate physical concepts in meaningful ways (Novak, 2010; Chi, 2009; Linn & Eylon, 2011). Unlike conventional approaches that often isolate concepts and prioritize computational fluency, conceptual frameworks aim to integrate knowledge, support metacognitive reflection, and strengthen cognitive connections across topics.

While prior studies have addressed conceptual tools in general physics instruction, fewer works have focused specifically on their integration in teaching motion. This article seeks to fill that gap by examining the pedagogical use of such tools in enhancing students' understanding of motion.

Furthermore, integrating recent learning theories—such as Conceptual Change Theory, Constructivism, and Cognitive Load Theory—into instruction provides a foundation for designing learning experiences that support conceptual restructuring and durable knowledge.

This article presents a theoretical-practical exploration of how conceptual frameworks can be systematically employed to improve student learning of motion concepts. It outlines key motion principles, contrasts traditional and conceptually driven pedagogy, and provides practical classroom strategies—drawn from both educational theory and reflective teaching experience. In doing so, it bridges the gap between research and practice.

Despite several studies exploring conceptual tools in physics education, this paper targets a specific research gap: (a) the lack of an integrated and sequenced framework that combines multiple conceptual tools (concept maps, mental models, simulations, and motion diagrams) specifically for teaching motion; (b) this gap matters because persistent misconceptions in motion directly affect students' problem-solving ability and long-term scientific reasoning; and (c) the contribution of this article lies in presenting a structured framework that connects learning theories to teacher-facing strategies and assessment criteria — going beyond scattered prior studies.
This article represents a theoretical-practical contribution. Its primary novelty lies in the structured integration of multiple conceptual tools—such as concept maps, mental models, and simulations—specifically applied to motion instruction.

2. Fundamental Concepts of Motion in Physics

Motion is one of the most essential and pervasive phenomena in the physical world, forming a core component of both classical mechanics and modern theoretical physics. Understanding motion requires the precise definition and interrelation of several key concepts, such as position, displacement, velocity, and acceleration, as well as a solid grasp of Newton's laws, which govern the dynamics of objects under the influence of forces. This section provides a foundational overview of the types of motion and their associated quantities, forming the basis for exploring more advanced instructional approaches.

2.1 Types of Motion

Motion in physics can be broadly classified into three main categories, each with distinct characteristics and applications: linear motion, rotational motion, and oscillatory motion.

Linear (Rectilinear) Motion involves an object moving along a straight path, either at a constant velocity or under acceleration. Examples include a car traveling on a highway or a falling object under the influence of gravity. This type of motion is typically analyzed using kinematic equations that describe the relationship between displacement, velocity, acceleration, and time (Serway & Jewett, 2018).

Rotational Motion occurs when an object rotates around a fixed axis. This type of motion is observed in systems ranging from spinning wheels to planetary rotation. Key quantities in rotational motion include angular displacement, angular velocity, angular acceleration, and torque (Young & Freedman, 2020).

Oscillatory Motion refers to periodic back-and-forth movement around an equilibrium point, as seen in pendulums, springs, or sound waves. Fundamental parameters such as amplitude, frequency, period, and phase characterize these systems, particularly in simple harmonic motion (Tipler & Mosca, 2008).

2.2 Key Kinematic and Dynamic Quantities

The motion of an object is described using several interrelated physical quantities, each playing a distinct role in analysis and prediction.

Position denotes the spatial location of an object relative to a reference frame. It is often represented using Cartesian or polar coordinates and varies as a function of time (Knight, 2017).

Displacement is the vector quantity representing the change in position over a specified time interval. Unlike distance, displacement conveys both magnitude and direction (Giancoli, 2018).

Velocity refers to the rate of change of displacement with respect to time. It can be expressed as average velocity over an interval or instantaneous velocity at a specific point in time. Understanding velocity is crucial for analyzing uniform and accelerated motion (Serway & Jewett, 2018).

Acceleration is defined as the rate of change of velocity over time. It can be constant (uniform acceleration) or variable, and it plays a central role in the study of dynamics. Acceleration is also a vector, meaning that changes in either magnitude or direction constitute acceleration (Young & Freedman, 2020).

2.3 Applications and Relevance

The concepts of motion have extensive relevance across scientific and technological domains:

In mechanical engineering, analyzing the motion of components informs the design of machines and structures.

In astronomy, understanding planetary and orbital motion enables accurate predictions of celestial events.

In biomechanics, motion analysis helps in understanding the movement patterns of organisms and enhancing performance in sports or rehabilitation.

In transportation and robotics, precise motion modeling is essential for control systems and safety mechanisms.

Establishing a strong conceptual foundation in these motion principles is critical not only for succeeding in physics education but also for applying scientific knowledge in real-world problem-solving. This foundation also prepares students to explore more advanced topics in mechanics, electromagnetism, and thermodynamics.

3. Conceptual Frameworks and Their Role in Teaching Motion

Conceptual frameworks have emerged as transformative tools in science education, offering structured approaches to facilitate students' understanding of complex and abstract ideas. In the context of motion, a domain where misconceptions are persistent and often resistant to traditional instruction, conceptual frameworks help learners build coherent mental models, integrate knowledge, and develop deep conceptual insight.

The effectiveness of these frameworks is grounded in cognitive theories of learning.

Conceptual Change Theory explains how students replace intuitive but incorrect beliefs with scientific ones when faced with cognitive conflict. Constructivist perspectives highlight the importance of active engagement and scaffolding new knowledge on prior understanding. Moreover, Cognitive Load Theory supports the structured use of visual tools and simplified representations to reduce working memory overload. These theories provide a strong foundation for using conceptual frameworks in motion instruction Fyfe, McNeil, Son, and Goldstone (2014) argue that concreteness fading—starting with concrete materials and gradually transitioning to abstract representations—can enhance science learning by grounding abstract thinking in perceptual experiences and promoting generalizable conceptual understanding.

Mental models are internal cognitive structures that learners use to interpret and predict physical phenomena. For example, some students hold an 'impetus-like model' of motion, assuming that continuous force is required to sustain motion, which contrasts with the Newtonian model of inertia. Such models have been extensively studied in conceptual change research [1].

3.1 Defining Conceptual Frameworks in Physics Education

Conceptual frameworks refer to a set of cognitive tools, instructional strategies, and visual representations that support the organization and assimilation of scientific knowledge. Rather than presenting information in isolated fragments, these frameworks foster holistic thinking by emphasizing the relationships among concepts and anchoring new knowledge in prior understanding.

In physics education, key components of conceptual frameworks include:

Concept Maps: Graphical tools that visually represent the hierarchical and relational connections between concepts. These maps assist students in identifying linkages between foundational ideas such as force, velocity, and acceleration.

Mental Models: Internal cognitive structures that students use to interpret and predict physical phenomena. They function as simplified mental representations of reality, enabling learners to explain events, anticipate outcomes, and make decisions in problem-solving contexts. In physics education, students often rely on mental models that may diverge from scientific principles, such as the "impetus model," where motion is incorrectly believed to require a continuous force. Accurate mental modeling is particularly crucial when grappling with Newtonian mechanics, because students must transition from intuitive, everyday conceptions of force and motion to formalized scientific models based on inertia, acceleration, and Newton's laws. Identifying, confronting, and reconstructing these mental models are therefore essential steps in fostering conceptual change and achieving a deeper understanding of motion.

Computer Simulations: Interactive digital environments that allow learners to manipulate variables and observe real-time outcomes. Simulations make invisible forces and motion observable and testable.

Visual Representations: Diagrams, graphs, and schematic illustrations (e.g., free-body diagrams, motion graphs) that translate abstract quantitative relationships into accessible visual formats.

These tools support conceptual learning by enabling students to organize knowledge meaningfully, challenge existing misconceptions, and develop scientifically accurate understandings. Kokkonen and Schalk (2021) argue that while the concreteness fading instructional sequence is appealing, its effectiveness is highly dependent on the nature of the domain-specific representations and instructional goals, particularly in science subjects such as physics.

3.2 Traditional Instruction vs. Conceptual Frameworks

Traditional physics instruction often emphasizes algorithmic problem-solving and formula memorization, with limited attention to the conceptual underpinnings of physical laws. While this approach may yield short-term procedural competence, it frequently fails to cultivate transferable understanding or long-term retention.

In contrast, instruction grounded in conceptual frameworks prioritizes:

Concept discovery over rote memorization

Cognitive engagement over passive reception

Relational understanding over fragmented facts

Table 1 presents a comparative summary of these two approaches under the title "Comparison of Traditional and Conceptual Instruction in Physics", outlining their main characteristics and pedagogical implications:

Table 1 "Comparison of Traditional and Conceptual Instruction in Physics"

Feature	Traditional Instruction	Conceptual Frameworks
Emphasis on memorizing equations	High	Low
Use of visual and interactive tools	Minimal	Extensive
Encouragement of conceptual reasoning	Low	High
Facilitation of cross-concept integration	Limited	Strong
Impact on student engagement	Often low	High

These shifts align with modern theories of meaningful learning and support the use of scaffolding strategies to promote integrative thinking**.**

3.3 Applications of Conceptual Frameworks in Teaching Motion

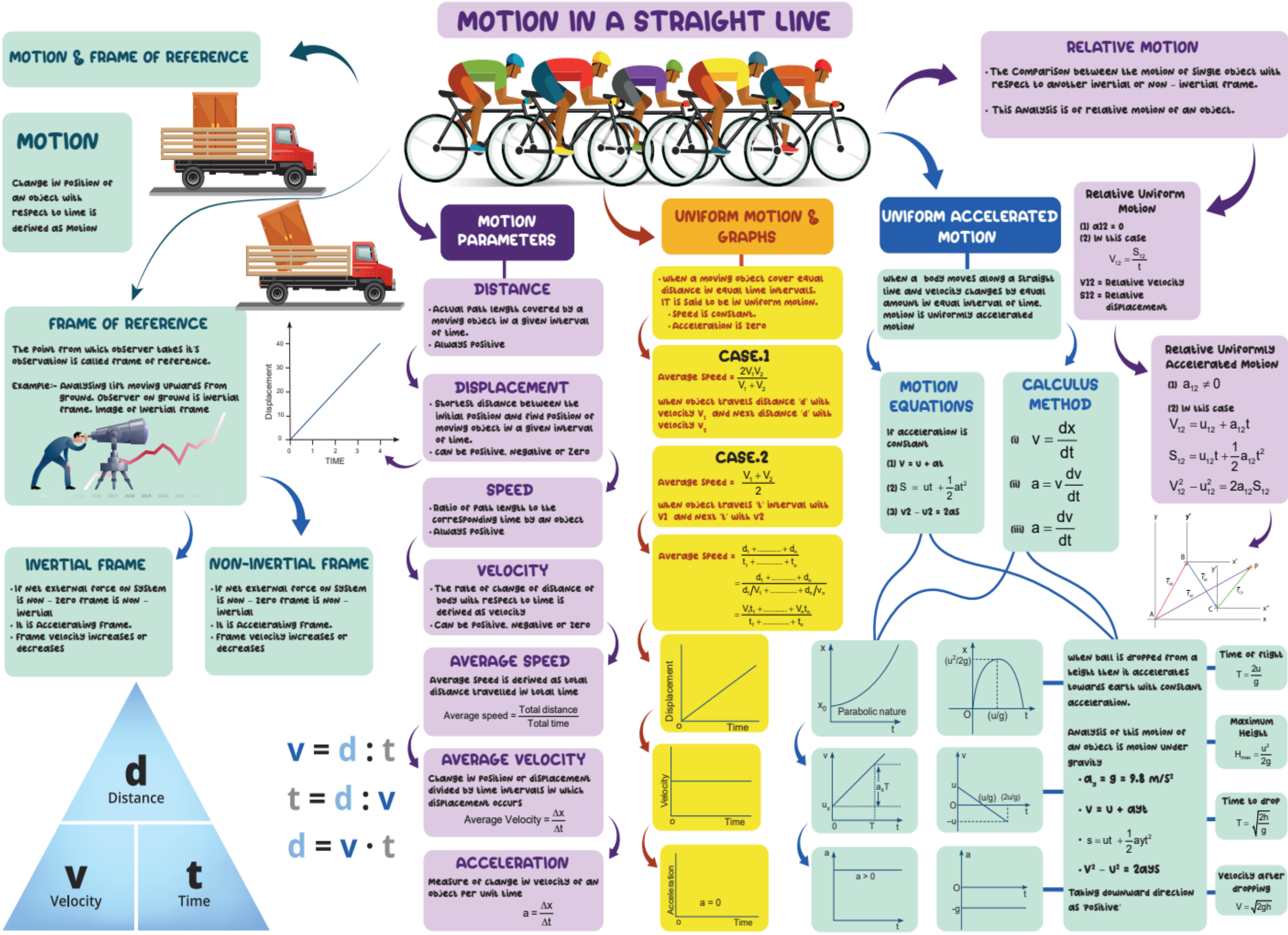
The following instructional tools exemplify the use of conceptual frameworks to teach motion more effectively:

- Motion Diagrams: Visual sequences depicting an object's position, velocity, and acceleration over time. These diagrams help clarify differences between uniform and accelerated motion and support the analysis of kinematic graphs.
- Mathematical Modeling: Encouraging students to derive and apply motion equations based on experimental data fosters both procedural fluency and conceptual understanding. This approach deepens students' grasp of Newton's laws and projectile motion. Recent experimental research has demonstrated that Conceptual Problem Solving (CPS) techniques significantly enhance students'

conceptual understanding of Newton's laws compared to traditional direct instruction (Diyana & Sutopo, 2024).

- Interactive Simulations: Tools such as PhET allow students to manipulate variables like mass and force in real-time. These simulations provide immediate feedback and make abstract relationships tangible. Recent studies suggest that animations grounded in conceptual metaphors and embodied cognition can significantly enhance students' understanding of complex physical concepts, particularly when algebraic reasoning is involved (Oosterwijk, 2022).

Concept Maps: For example, a concept map linking force, mass, and acceleration can reinforce Newton's second law and help correct common misconceptions. Figure 1 illustrates a conceptual map applied to the topic of motion in a straight line.



.Figure 1- An Example of a Concept Map in Physics Learning

These frameworks do not merely supplement instruction; they reshape how students think about physics. By encouraging inquiry, reflection, and knowledge integration, conceptual frameworks move learners beyond superficial familiarity toward genuine understanding.

Although this article does not present new empirical data, the selection and categorization of strategies are grounded in two main sources: (1) a systematic review of literature and empirical evidence on physics concept learning, and (2) classroom-based implementation experiences and feedback. Specifically, the strategies draw on tested approaches such as

Model Analysis [1], the concreteness fading sequence (Fyfe et al., 2014), embodied learning (Lindgren et al., 2016), and studies on simulations and video analysis (Oosterwijk, 2022; Linn & Eylon, 2011). In the manuscript, each strategy is supported with relevant references and classroom-based examples.

To maintain transparency, it is important to clarify how the conceptual strategies presented in this article were selected. These approaches are derived from a combination of the authors' classroom teaching experience, analysis of successful instructional practices, and synthesis of relevant findings in physics education literature. Although the article does not present new empirical data, its recommendations are built upon tested methods and documented research.

4. Practical Strategies for Effective Teaching of Motion

Effectively teaching motion requires pedagogical strategies that bridge abstract theoretical concepts with students' lived experiences and cognitive frameworks. Given the persistent conceptual difficulties learners face in understanding motion—particularly in areas such as velocity, acceleration, Newtonian dynamics, and projectile motion—it is essential to employ diverse, evidence-based instructional approaches.

This section outlines multiple evidence-informed strategies—drawn from instructional practice and literature synthesis—that can help educators improve students' conceptual understanding of motion.

4.1 Connecting Motion Concepts to Real-World Phenomena

Grounding abstract concepts in everyday experiences can significantly improve students' ability to relate to and internalize physical principles. By drawing from familiar contexts, instructors can make motion concepts more accessible and engaging. Table 2 provides an overview of real-life examples and suggested classroom activities that can be used to support the teaching of motion concepts. The table links key physical principles—such as velocity and acceleration, projectile motion, oscillatory motion, and friction—to both experimental classroom practices and familiar everyday contexts, thereby helping students connect theoretical knowledge with practical experiences.

Table 2: Real-Life Examples and Suggested Activities for Teaching Motion

Physical Concept	Classroom Activity	Real-World Example
Velocity and Acceleration	Analyze video clips showing vehicles changing speed under different conditions.	A cyclist accelerating, a car breaking on a highway
Projectile Motion	Perform ball toss experiments from varying heights and measure the trajectory.	Kicking a soccer ball, throwing a stone into a pond
Oscillatory Motion	Use pendulums to investigate amplitude and period	Swinging on a playground swing, the motion of a clock pendulum
Friction	Explore how different surfaces affect motion using inclined planes	Sliding a shoe on carpet, wood, or ice

These contextualized activities align with constructivist learning principles, helping students anchor formal physics content in prior experience and everyday intuition. Such contextualized activities not only improve comprehension but also reinforce the relevance of physics to daily life, thereby boosting students' motivation and retention.

4.2 Utilizing Educational Technologies and Simulation Tools

Digital technologies offer powerful affordances for visualizing and experimenting with motion concepts in ways that are otherwise difficult to replicate in a typical classroom. Interactive simulations allow for repeated experimentation under controlled and idealized conditions. Recent studies have shown that integrating embodied scaffoldings within interactive learning environments can improve conceptual learning and spatial reasoning, particularly when learners interact with abstract scientific content (Zeng et al., 2025). Table 3 summarizes recommended simulation software for teaching motion, outlining their key features and instructional applications. These tools range from accessible web-based modules to advanced modeling platforms, enabling teachers to illustrate motion concepts through interactive experiments, video analysis, and high-precision simulations.

Table 3: Recommended Simulation Software for Teaching Motion

Software	Key Features	Instructional Applications
PhET Simulations	Free, web-based, interactive modules for physics learning	Investigate Newton's laws, forces, and motion in two dimensions
Algodoo	User-friendly platform for simulating physical interactions	Design and explore custom motion scenarios and interactions
Tracker	Video analysis software for kinematic studies	Extract real-time velocity and acceleration data from recorded experiments
COMSOL Multiphysics	Advanced physics modeling tool	Simulate real-world systems with high precision

The integration of these tools supports inquiry-based learning, enhances students' visual-spatial reasoning, and facilitates the exploration of motion principles within interactive, low-risk environments. Moreover, by offering dynamic visual representations of otherwise abstract or invisible forces, such tools can help reduce cognitive load and promote deeper conceptual understanding.

4.3 Integrating Laboratory Experiments and Physics Workshops

Hands-on experimentation remains one of the most effective methods for reinforcing conceptual understanding. Physical experiments provide direct experience with forces and motion, enabling students to connect theoretical models with observable outcomes. Table 4 compares physical experiments and virtual simulations, highlighting their differences in interaction, accuracy, cost, and replicability. This comparison illustrates the complementary role of both approaches in supporting effective physics instruction.

Table 4: Comparing Physical Experiments and Virtual Simulations

Feature	Physical Experiments	Virtual Simulations
Interaction with physical materials	High	None
Accuracy and control of variables	Limited (subject to physical error)	High (idealized conditions)
Cost and resource requirements	High	Low or free
Replicability and consistency	Moderate	Very high

Blending physical and virtual methods can create a synergistic learning environment. For example, students may conduct a simple pendulum experiment in class, and then use a simulation to explore how altering gravity or string length affects motion variables that may not be feasible to change physically.A blended approach that combines physical experimentation with virtual tools can optimize both realism and conceptual clarity.

4.4 Integrated Implementation Framework for Motion Instruction

To support teachers in implementing the above strategies in a coherent way, we propose the following step-by-step framework:

Diagnose Preconceptions: Use diagnostic questions or short quizzes to uncover misconceptions.

Introduce Concepts through Context: Connect motion principles to real-world phenomena.

Explore through Simulations: Use PhET, Tracker, or Algodoo to manipulate variables and visualize motion.

Reinforce with Concept Mapping: Create visual maps linking forces, acceleration, and kinematics.

Consolidate with Hands-on Activities: Conduct simple classroom experiments or project-based workshops.

Assess Conceptual Change: Use qualitative and quantitative tools to evaluate student understanding.

This sequence can be adapted flexibly to suit different levels, curricula, or resource constraints.

5. Challenges and Solutions in Teaching Motion with Conceptual Frameworks

Teaching motion concepts using conceptual frameworks offers significant pedagogical advantages, yet it also presents a set of practical challenges that educators must navigate to ensure effective implementation. This section examines prevalent obstacles including student misconceptions, curriculum constraints, and resource limitations, and proposes evidence-based strategies to address them.

5.1 Common Student Misconceptions and Instructional Interventions

Students frequently enter physics courses harboring entrenched misconceptions about motion, such as the belief that a continuous force is necessary to sustain motion or that heavier objects fall faster than lighter ones. These misconceptions can significantly impede conceptual change and the acquisition of scientifically accurate understanding. Table 5 presents common misconceptions about motion alongside their scientific explanations and suggested intervention strategies. This alignment helps educators address students' misunderstandings effectively and reinforce accurate conceptual understanding.

Table 5: Common Misconceptions and Suggested Interventions

Misconception	Scientific Reality	Recommended Correction Strategy
Objects require a force to keep moving	Newton's First Law states that objects maintain motion unless acted upon	Use frictionless surface experiments to demonstrate inertia
Heavier objects fall faster than lighter ones	In a vacuum, all objects experience the same acceleration due to gravity	Conduct Galileo-style dropping experiments or use simulations
Acceleration always aligns with the direction of motion	Acceleration can oppose motion direction (e.g., braking)	Analyze projectile motion and vector components of acceleration

Correcting these misconceptions requires not just content delivery, but conceptual conflict and active engagement. Framework-based strategies—such as guided inquiry, simulations, and discussion—can help students restructure their internal models.

5.2 Instructional and Structural Barriers

Despite their potential, conceptual frameworks often face implementation challenges at both the classroom and institutional level. These include:

- Limited instructional time restricts opportunities for in-depth conceptual exploration.
- Insufficient access to laboratory equipment hampers the ability to conduct hands-on experiments.
- Teacher preparedness gaps result in inconsistent application of conceptual methods.
- Additionally, shifting from familiar rote learning approaches to student-centered conceptual instruction can initially cause discomfort or disengagement, especially if students are not used to inquiry-based learning.

5.3 Strategies for Overcoming Challenges

- Addressing these challenges requires both strategic planning and system-level support. The following approaches are recommended:

- Integrate concise, targeted conceptual activities that fit within existing time constraints, such as focused group discussions or brief inquiry prompts.
- Leverage free and accessible digital simulations (e.g., PhET) to supplement or replace physical experiments where resources are limited.
- Provide professional development and workshops to enhance teachers' knowledge and confidence in conceptual pedagogy.
- Cultivate a classroom culture that encourages questioning and reflection, easing student transition to active learning modes.
- Furthermore, embedding conceptual frameworks systematically within the curriculum through inquiry-based tasks, interdisciplinary projects, and collaborative learning can foster sustainable instructional transformation. Table 6 outlines common barriers to the conceptual teaching of motion and proposes practical solutions to overcome them. By addressing constraints such as time, resources, teacher preparation, and student resistance, the table highlights

strategies that can make conceptual instruction more feasible and effective in classroom settings.

- Table 6: "Barriers and Solutions in Conceptual Teaching of Motion"

Barrier	Practical Solution
Limited time	Use short, focused conceptual tasks within routine lessons (e.g., 10-minute discussions, mini-experiments)
Lack of lab resources	Leverage free simulations (e.g., PhET, Tracker) to supplement or replace physical experiments
Insufficient teacher training	Offer professional development, peer coaching, and access to practical instructional guides
Student resistance	Build gradual exposure to conceptual tools; combine with familiar formats to ease transition

- In addition, school systems should provide structured support such as integrated curriculum models, shared simulation libraries, and time allocated specifically for concept-based learning.
- Sustained implementation also requires a classroom culture that values inquiry, tolerates error, and encourages collaborative reasoning.

5.4 Toward Systemic Integration

For long-term success, the use of conceptual frameworks should be embedded into curriculum design—not treated as optional supplements. This includes aligning assessments with conceptual goals, training pre-service teachers in these methods, and engaging administrators in supporting pedagogical innovation.When applied systematically, conceptual frameworks not only improve understanding of motion but also foster transferable scientific thinking.

Conclusion

Teaching motion in physics is a foundational component of science education that significantly shapes students' understanding of natural laws. However, the persistence of misconceptions about motion, coupled with pedagogical and implementation challenges in classroom settings, often impedes effective learning. As this article has shown, persistent student misconceptions—such as those related to inertia, free fall, and acceleration—necessitate instructional strategies rooted in conceptual understanding rather than rote memorization. Embodied learning environments that engage sensorimotor systems have been shown to significantly improve retention of conceptual physics knowledge and reduce persistent misconceptions about motion, such as the "circular impetus" model associated with centripetal force (Lindgren et al., 2016).

This article has presented a theoretical-practical approach that synthesizes conceptual tools—such as simulations, concept maps, mental models, and motion diagrams—with classroom-tested strategies. Grounded in cognitive learning theories, these tools can foster meaningful understanding of motion by addressing misconceptions, supporting visual reasoning, and promoting active knowledge construction.

Incorporating conceptual frameworks into motion instruction offers a powerful means to engage learners, support cognitive development, and promote retention of core physical principles .Successful implementation requires more than just access to tools—it involves redesigning classroom practices, aligning assessments, and preparing educators through professional development.

The primary contribution of this paper lies in offering a structured and theory-informed model for integrating multiple conceptual tools specifically within the context of motion instruction in physics education.

Future Research Directions

While this paper offers practical and theoretical guidance, further empirical studies are needed to assess the long-term effects of conceptual frameworks on student learning. Future research could explore:

- The effectiveness of these frameworks across different learning styles (e.g., visual, kinesthetic, analytical learners)
- Comparative studies in diverse cultural or curricular contexts
- Longitudinal studies to track conceptual retention over time
- The role of teacher training in the successful adoption of these methods
- Integration of AI-based adaptive simulations in motion education

Such research would help strengthen the evidence base and guide future instructional design in physics education.

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